APPLICATION OF COAL ASH-BENTONITE MIXTURES AS LANDFILL LINER

A Thesis submitted in partial fulfillment of the requirements for the award of the degree of

Master of Technology
In
Civil Engineering
(Geotechnical Engineering)

KANANIKA NAYAK

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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KANANIKA NAYAK
(213CE1049)

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Under The Guidance Of
Prof. S P Singh

Department of Civil Engineering

National Institute of Technology, Rourkela

Odisha – 769008, India

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DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA- 769008, ODISHA, INDIA

This is to certify that the thesis entitled, "**Application of Coal ash-bentonite Mixtures as Landfill Liner**" submitted by **Kananika Nayak** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Geotechnical Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Place: Rourkela
Date:

Research Guide
Dr. S P Singh
Professor
National Institute of Technology
Rourkela

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KANANIKA NAYAK

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NOTATION	DESCRIPTION
G	Specific Gravity
C_C	Coefficient of curvature
C_U	Coefficient of uniformity
LL	Liquid Limit,%
PL	Plastic Limit,%
SL	Shrikage Limit,%
L_S	Linear Shrinkage Index,%
FSI	Free Swell Index,%
OMC	Optimum Moisture Content,%
MDD	Maximum Dry Density, g/cc
UCS	Unconfined Compressive Strength, kPa
k	Coeffiecient of Permeability, cm/sec

ABSTRACT

Landfills are the most popular municipal solid waste disposal system. The landfill liner is designed to isolate the waste from the soil beneath to minimize the passage of leachate into the groundwater. Usually compacted liner materials consist of soil rich in clay minerals for their low hydraulic conductivity. This study is an attempt to assess the use of a waste material, coal ash(fly ash and pond ash) as a potential liner material by mixing it with bentonite in various percentages ranging from 2-20%. Both pond ash and fly ash are non-plastic and possess very low shrinkage. With the addition of bentonite in the mixture, the plasticity is expected to increase and the coal ash is expected to reduce the swelling and shrinkage, preventing formation of any cracks. Due to its swelling properties,bentonite in the mixture is expected to act as a self-sealing, low permeability hydraulic barrier.To determine the viability of coal ash- bentonite mixture as a liner material, the mixture was compacted at its optimum moisture content and maximum dry density and laboratory tests were conducted to obtain the various geotechnical parameters such as plasticity, shrinkage, permeability, free swell index, c, ϕ and unconfined compressive strength.It was found that a compacted mixture of bentonite with fly ash and pond ash with the percent of bentonite in the mixture between 12-20% had the required hydraulic conductivity and strength properties to be used as a liner material.

Keywords : fly ash, pond ash, bentonite, landfill liner, permeability

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A compacted clay liner or landfill liner comprises, compacted cohesive soil having no seepage. The main goal is to decrease porosity and soil permeability. Landfills are the most popular municipal solid waste disposal system.

Fig.1.1: Compacted Clay Liner

The design of liner is made so as to isolate the waste from the environment minimizing the passage of leachate into the groundwater**.** To ensure this the important characteristics for compacted landfill liners are selection of materials, hydraulic conductivity, strength, compressibility and contaminant retention capacity. Usually soil rich in clay minerals are used as compacted liner materials for their low hydraulic conductivity which is required to be less than

1.00×10^ -7 cm/s (Daniel, 1987; 1990; Benson and Trast, 1995). Instead of clay, mixture of expansive soil such as bentonite with fly ash and pond ash can be used as compacted barriers.

1.2 COAL ASH

In India, thermal power is the chief source of energy and produces nearly 70 percent for total energy production. The coal ash generated from all the existing thermal power plants is over 100 million tons per year (Gulhati & Datta, 2005). The production of fly ash has greatly surpassed its disposal because of its low utilization in various fields. Hence, major quantity of fly ash has to be disposed off on land in ash ponds which are created to reduce stress on the environment.

Fig.1.2: Coal ash deposits

The fly ash as well as bottom ash produced by the plant is generally disposed of in an ash pond in a form of slurry in a ratio varying from 1 part ash and 6 to 10 parts of water which are located within few kilometers distance from the power plant. This ash is called pond ash.

Fig.1.3: Ash pond

Fly ash is generated in tons as a residue from burning of coal in the power plants. It comprises the fine particles that rise with the flue gases generally captured by electrostatic precipitator. Bottom ash is that portion of the ash which does not rise and together with fly ash it is called as pond ash which is removed from the bottom of the furnace. The components of fly ash vary according to the type of coal being burned. But mainly all fly ash include substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO), both being the common ingredients in many coal-bearing rock strata.

Previously fly ash was simply entrained in flue gases and released into the atmosphere, which proved to be harmful for our environment. They must either be disposed or recycled, thus creating another major concern growing each year. Research works are being done to find methods of suitable Industrial use of fly ash and pond ash in a large scale.

1.3 BENTONITE

Bentonite is a clay formed as a result of chemical weathering of volcanic ash. It consists predominantly of smectite minerals, usually montmorillonite [$Si_8Al_4O_{20}$(OH)4.nH2O]. The clay mineral montmorillonite is composed of two silica sheets and one alumina sheet as shown in fig.1.4.

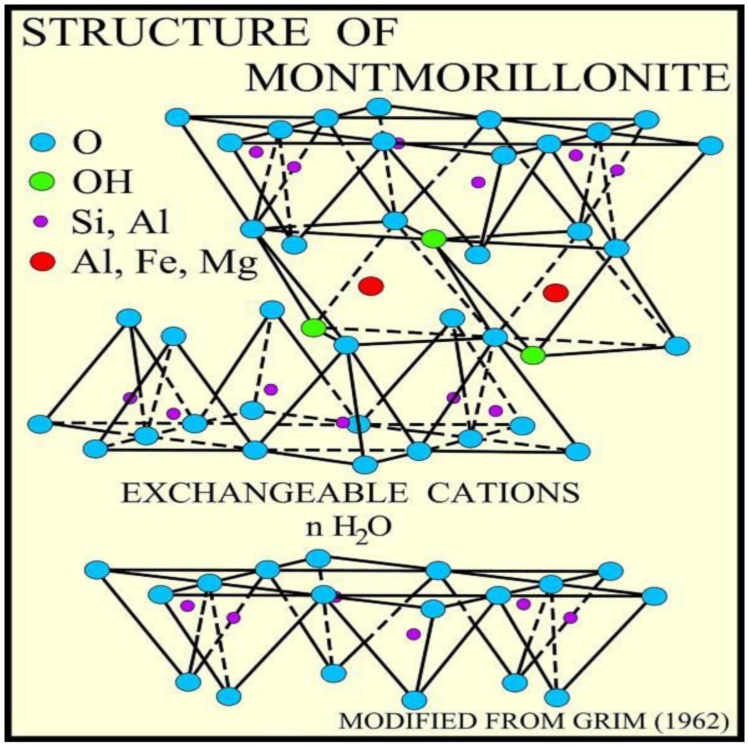

Fig 1.4:Structure of Montmorillonite(Grim 1962)

The interlayer bonding between the tops of silica sheets is mainly due to weak Vander waals forces which is equivalent to almost no bonding. Hence water and other polar molecules readily enter in between the layers resulting in its extremely high swelling properties. They easily shrink once water is removed from the lattice.

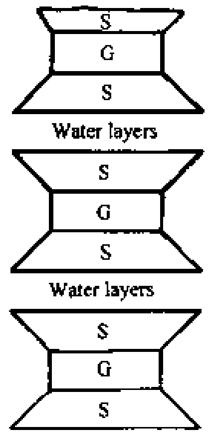

Fig. 3.5: Symbolic structure of montmorillonite (Advanced Soil Mechanics, B M Das)

Due to its swelling properties,bentonite provides as a self-sealing, low permeability hydraulic barrier. Thus can be used to line the base of landfills. Soil-bentonite mixes are frequently used as impervious blanket in waste containment system owing to the low hydraulic conductivity of clay soils.

1.4 MATERIAL SUITABILITY

The current project aims at finding an accurate mixture of fly ash and bentonite as well as pond ash and bentonite, feasible for being used as compacted clay liner. The factors considered for liner material suitability are:

- Efficiency
- Resistance to damage
- Longevity
- Availability

Even though coal ash and bentonite have extremely opposite properties, when mixed together they show complimentary behavior. Fly ash and pond ash are highly permeable but with the addition of bentonite the hydraulic conductivity can be reduced to fulfill the design criteria.

Similarly, high swelling and shrinkage behavior of bentonite posses the danger of formation of cracks, which can be stabilized by addition of coal ash as it would minimize the fine fraction in the mixture. Bentonite being an excellent sealant helps check the passage of leachate to the ground water. By compacting the coal ash-bentonite mixture at the optimum range of dry density and moisture content the bonding between the particles is enhanced which in turn increases the strength and longevity of the liner. The bulk availability of coal ash helps reducing the cost of raw materials required for liner as well as providing their safe disposal in a large scale.

CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

Use of sanitary landfills for waste containment is one of the oldest and most popular waste disposal technique. Many researchers have investigated the potential of various materials to be used as liner material. A lot of work has been done to engineer an efficient and cost effective liner system that would act as a barrier between the waste and the environment. In this chapter a detailed review of the research work conducted till date regarding compacted clay liner is presented and discussed. More importance has been given to the use of waste product or materials available abundantly in nature so as to reduce the stress on environment caused due to the waste generation from various sources.

2.2 SPECIFICATIONS OF COMPACTED CLAY LINER

Craig H. Benson et al(1994) described a database which was used to evaluate relationships between hydraulic conductivity, compositional factors, and compaction variables and to identify minimum values for soil properties that are likely to yield a geometric mean hydraulic conductivity $\leq 1\times10^{-7}$ cm/s. The material specifications obtained from the analysis is presented in table 2.1.

Table 2.1 liner specifications for the soil

Property	Minimum(%) for $k \leq 1.00 \times 10^{-7}$ cm/s
Liquid Limit	20
Plasticity Index	7
% Fines	30
% Clays	15
Activity	0.3

Craig H. Benson and John M. Trast(1995) conducted hydraulic conductivity tests on thirteen compacted clay liners at landfills throughout the U.S. and showed that a distinct set of zones exist in the compaction plane (dry unit weight vs. water content) that correspond to similar hydraulic conductivity for all of the soils. These zones fall roughly parallel to contours of constant initial saturation(degree of saturation at compaction), with a lower hydraulic conductivities occurring at higher initial saturation. A graph of hydraulic conductivity vs. initial saturation showed an inverse relationship between them and illustrated that lower hydraulic conductivities are achieved for higher compactive effort.

Lakshmikantha and Shivapullaiah(2006) evaluated the suitability of different types of locally available materials for their potential as liner material. Studied the advantages and disadvantages of four materials namely; red earth with 20% bentonite, illite with 20% bentonite, fly ash with 20% bentonite and illite alone, stabilized with 1% by weight of lime along with the chemical compatibility of the materials to electrolyte solution (0.5 N NaCl), alkaline solution (0.5 N NaOH), acid(0.5 N HCl) and organic fluid (CCl_4). To meet the EPA requirement of hydraulic conductivity of soil liners to be equal to or less than 1×10^{-7} cm/sec :-

- The silt and clay content in the soil should be least 15-20%.
- The PI should be > 10%.
- The gravel content should not be more than 10%.

The material should not contain soil particles for chunks of rock larger than 1 to 2 inches in diameter.

According to the results non plastic fly ash becomes plastic on addition of lime which slightly increased the compression index, lowering the hydraulic conductivity.

Bello(2013) The basic attributes of a suitable liner are presence of significant amount of clay minerals and having a hydraulic conductivity less than or equal to 1×10^{-7} cm/s**.**

2.3 COAL ASH AND BENTONITE AS LINER MATERIAL

Kamil Kayabali(1997) conducted tests on seven different ratios of bentonite to zeolite to obtain a mix ideal as landfill liner material. Owing to its swelling ability, the bentonite content serves as pore-sealant as it is saturated. The optimum water contents and corresponding dry densities ranged from 33 to 42% and 1.16 to 1.26 mg/ m^3, respectively. At the smallest ratio of B/Z (i.e., 0.05), the water content of the bentonite component was as high as 850% and full saturation was reached. The average range of hydraulic conductivity was 2×10^{-8} to 4×10^{-8} cm/s.

Ambarish Ghosh and Chillara Subbara(1998) studied the stabilization of a low lime fly ash with lime and gypsum. Large scale tests were conducted on the stabilized material designed to simulate field recycling conditions as closely as possible, and found to be a very effective means to control hydraulic conductivity and leachate characteristics. With proper proportioning of the mix, and adequate curing, the values of hydraulic conductivity on the order of 10^{-7} cm/s were achieved. Stabilized compacted low lime fly ash mixed with 10% lime and 1% gypsum and cured for 28 days could produce an impermeable layer useful for base layers or waste containment liners with permeability on the order of 8×10^{-8} cm/s from fly ash with permeability 4.5×10^{-5} cm/sec . For fly ash-lime-gypsum mixes, a molding water content in the range of OMC and OMC + 5% was specified for field control of fill moisture content . This molding water content on the wet side of optimum had the advantages of low hydraulic conductivity, reduced leaching, marginal variations of hydraulic conductivity and obviously better workability.

Brian G. Palmer et al(2000) evaluated the hydraulic conductivity of class F fly ash containing residual organic carbon and compacted specimens of class F fly ash mixed with sand, class C fly ash and bottom ash. The results showed that OMC of class F fly ash was 10% for modified effort and 15% for standard effort. The study showed that mixtures of Class F and C ashes combined with a coarse aggregate (e.g., bottom ash) can be compacted to achieve hydraulic conductivity near or below 10^{-7} cm/s at compaction water contents above optimum water content.

Mollamahmutoglu and Yilmaz(2001) mixed Catalagzi fly ash with bentonite at 5 to 30% by weight, to obtain less permeable liner material. With the increase in amount of bentonite, the MDD of the bentonite-fly ash mixtures increased at about same OMC, the permeability decreased, consolidated undrained shear strength parameters increased and the compressibility indices of the mixtures ranged from 0.009 to 0.019. It was concluded that a 20% bentonite-fly ash mixture proved to be a suitable liner material.

Prashanth et al(2001) examined the potential of pozzolanic fly ash as a hydraulic barrier in landfills by evaluating the geotechnical properties such as shrinkage, compaction, permeability, consolidation and strength characterisics.The results showed that fly ash do not crack as they posses very low shrinkage. Pozzolanic fly ash with lime exhibited low permeability on curing because of formation of gelatinous compound which blocked the pores, hence can be used as liner material to contain alkaline leachate.

Semra Coruh and Osman Nuri Ergun(2010) Investigated the safe and efficient disposal of the leachate containing zinc residue waste using industrial byproducts such as fly ash, phosphogypsum and red mud as liner material. The results demonstrated that fly ash and red mud performed better than phosphogypsum in reducing the heavy metal contents of leachate. These act as effective adsorbents for the removal of zinc ion.

Mishra et al (2010) Evaluated the Effect of the physical, chemical and mineralogical properties of the bentonites on the various consolidation parameters of 15 different soil–bentonite mixtures. The results showed the compression index(Cc) of the mixtures increased with the increase in liquid limit, free swelling and clay fraction of the bentonites, as well as with the liquid limit of the soil–bentonite mixtures. Coefficient of consolidation(Cv) for all mixtures increased with the increase in the consolidating pressure. The time for 50% of consolidation(t_{50}) of the mixture increased with the increase in liquid limit, swelling capacity and ESP of bentonite.

J.Alam et al (2012) studied that a 20% bentonite-fly ash mix can be safely used as liner material. Plain fly ash remained non-plastic until 20% bentonite was added to the mixture. Addition of bentonite enhanced the geotechnical properties of fly ash.

Kumar and Sharma(2004) concluded that in a bentonite-fly ash mixture the plasticity, hydraulic conductivity, swelling and shrinkage properties decreased and the dry unit weight and strength increased with the increase in fly ash content.

Sivapullaiah and Lakshmikantha(2004) based on their experimental results stipulated that compacted fly ash-bentonite mixtures show very less volume changes under different stress conditions. With the addition of bentonite the geotechnical properties of the fly ash such as cation exchange capacity improved.

Younus and Sreedeep (2012) indicated that up to 70% fly ash content can be used to satisfy the requirements of compacted landfill liners.

Satyanarayana et al (2013) conducted various geotechnical tests on bentonite-red soil mixes and identified that 10-15% dosage of bentonite satisfied the hydraulic conductivity and other functions as a liner material. At 10% bentonite content the soil exhibited low compressibility(w_L<35%) , medium plasticity(Ip= 7-15) and low swelling (FSI<20%). From 15-20% bentonite onwards it turned to intermediate compressible and high plastic(Ip>15) and medium swelling (FSI<20-35). With the increase in bentonite in the red soil-bentonite mix it became impervious(k<10^{-6} cm/s).

<u>CHAPTER 3</u>

EXPERIMENTAL WORK AND METHODOLOGY

3.1 INTRODUCTION:

Fly ash used for the experimental purpose was brought from RSP, Rourkela. Pond ash used was from NTPC, Angul and Bentonite was purchased from Rourkela market. Bentonite was mixed with the coal ash in 2,4,8,12 and 20% by dry weight and then compacted. Fly ash and Pond ash are the two types of Coal ash used for this project. The appropriate Bentonite-Fly ash mix, Bentonite-Pond ash mix and the range of compaction parameters was determined that would give the required hydraulic conductivity, strength characteristics and minimum desiccation crack for their use as liner material.

3.2 MATERIALS USED

3.2.1 Fly ash

Fly ash is micron-sized, glassy powder residue as a result of coal combustion in power plants. It is the 'fine' fraction of the ash carried upwards with the flue gases which is captured by the electrostatic precipitators. It is pozzolanic in nature and consists primarily of silica, alumina and iron. The chemical content of the coal burned (anthracite, bituminous and lignite) influences the chemical properties of fly ash. ASTM C618 defines and classifies it into class C and class F basing on the amount of calcium, silica, alumina and iron content. Class F fly ash is generated due to combustion of anthracite and bituminous coal. It has low lime(CaO) content i.e. < 20%. Whereas burning lignite or sub-bituminous coal yields Class C fly ash which generally contains more than 20% lime (CaO).The fly ash used here was collected from Rourkela Steel Plant, Odisha. It was oven dried at a temperature of 105˚C-110˚C, prior to the tests. The various properties were obtained and showcased in table 3.1.

Fig 3.1:Fly ash

3.2.2 Pond ash

Pond ash was obtained from the wet disposal of fly ash along with bottom ash as slurry, in engineered structures called ash pond. It is a waste product from boilers and contains relatively coarser particles. The pond ash used for this work was collected from NTPC Angul, Odisha. It was oven dried at a temperature of 105˚C-110˚C, prior to the tests. The various properties were obtained and showcased in table 3.1.

Fig 3.2: Pond ash

3.2.3 Bentonite

The bentonite used for the project work was Sodium bentonite which is a naturally occurring hydrated aluminum silicate clay. It exhibits extremely high swelling and water absorbency properties. Sodium bentonite has been successfully employed as a sealant for earthen darn structures in areas abundant with highly permeable soil. This is mainly because of its efficient water absorbency resulting in swelling ,thereby filling the existing air and water voids with a thick plastic mass. Also this plastic mass acts as a bonding agent for the soil particles during the compaction process.

Fig 3.3: Bentonite powder

Table 3.1: Physical properties of Fly ash, Pond ash and Bentonite

Physical parameter	**Fly ash**	**Pond ash**	**Bentonite**
Color	Grey	Light grey	Cream
Shape	Rounded/sub-rounded	Rounded/sub-rounded	Platy
Uniformity coefficient	5.71	8.15	-
Coefficient of curvature	1.27	0.83	-
Specific gravity	2.33	1.95	2.89
Plasticity Index(%)	Non-plastic	Non-plastic	236

3.3 DETERMINATION OF INDEX PROPERTIES

3.3.1 Determination of Specific Gravity

The specific gravity of fly ash, pond ash and bentonite were found out according to IS: 2720 (part- III, section-1)1980 by density bottle method. In case of bentonite kerosene was used as it is non-polar in nature.

The values obtained are listed in table 3.2

Table 3.2: Specific gravity of materials

Materials	**G**
Fly ash	2.33
Pond ash	1.95
Bentonite	2.89

3.3.2 Determination of Grain Size Distribution

Grain size distribution was obtained by performing sieve analysis for coarser particles and hydrometer analysis for finer particles according to IS 2720 (part-IV). The grain size distribution curves of fly ash, pond ash and bentonite are presented in figs. 3.4, 3.5 and 3.6 respectively.

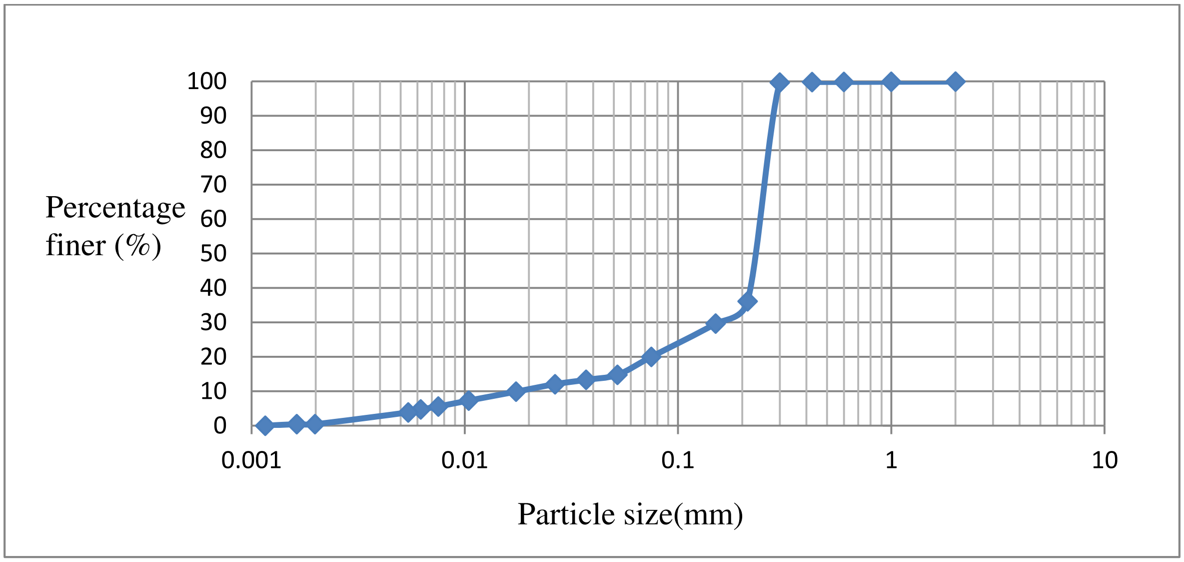

Fig. 3.4 Grain size distribution curve of fly ash

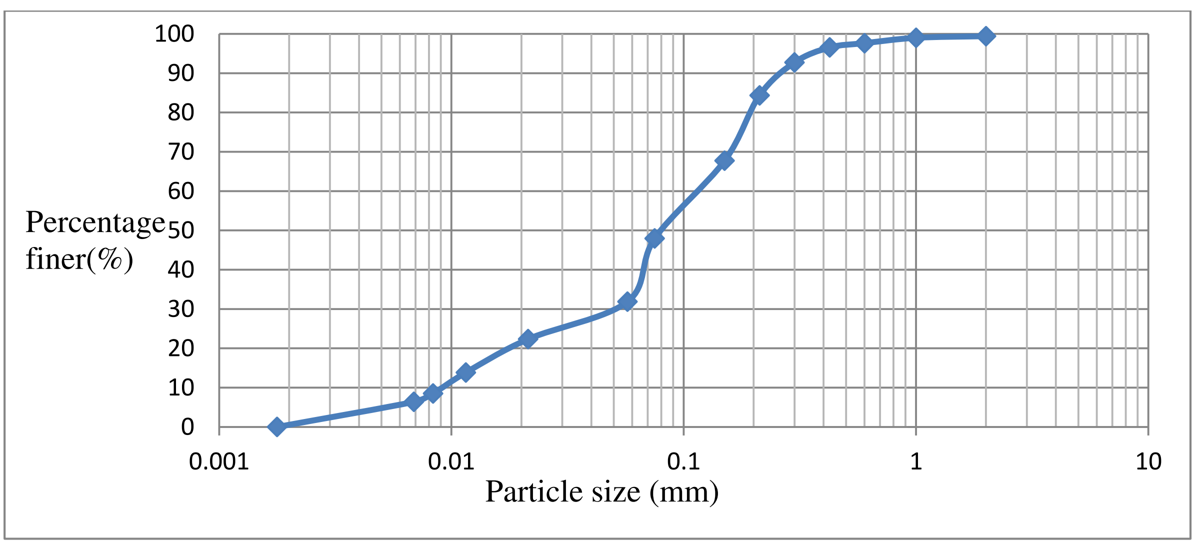

Fig.3.5 Grain size distribution curve of pond ash

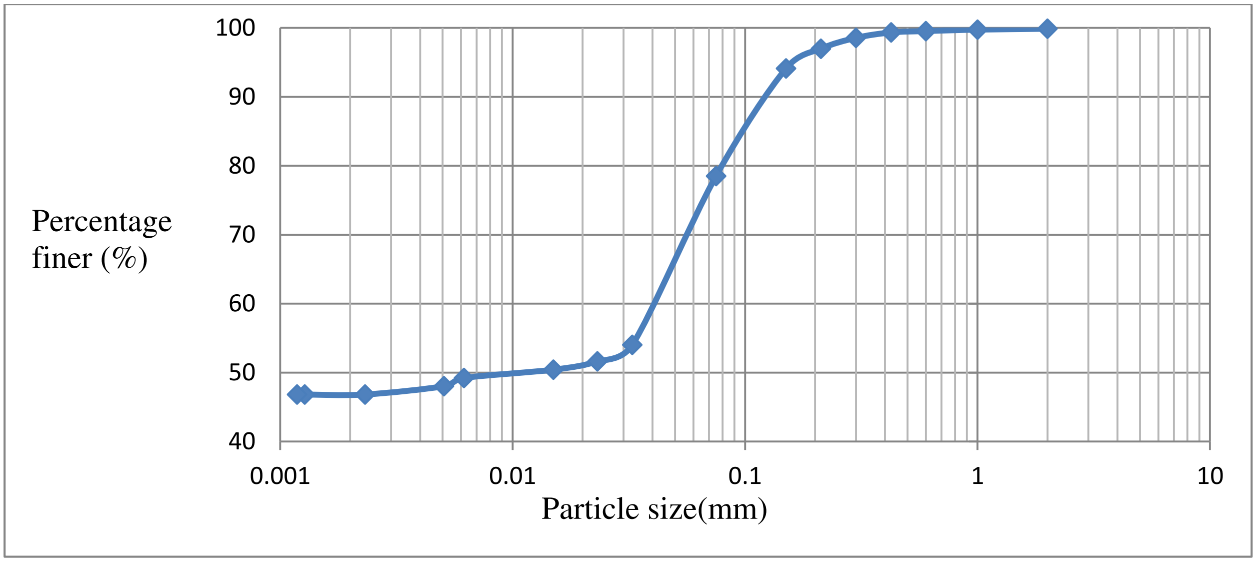

Fig.3.6 Grain size distribution curve of bentonite

3.4 DETERMINATION OF GEOTECHNICAL PROPERTIES

3.4.1 Determination of Atterberg Limits

The Liquid Limit and Plastic Limit of two sets of test samples consisting of six coal ash-bentonite mixtures each were determined.

3.4.1.1 Determination of Liquid Limit

For fly ash and pond ash Liquid limit tests were conducted by one point penetration method in a cone penetrometer as shown in fig 3.7, whereas for Bentonite, Casagrande's apparatus was used. Two sets of samples were prepared by mixing bentonite to fly ash and to pond ash, all the materials passing through 425µ IS sieve . About 120g of the mixtures were taken and mixed with water forming pastes which were left for 24 hours for maturing. Test for liquid limit was conducted according to IS 2720 (part V)-1985 in the Cassagrande's liquid limit device as shown in fig. 3.8. A portion of the paste was placed at the centre of the cup and spread out evenly, after which a groove was made by the grooving tool. The cup was dropped by turning the handle at the rate of 2 revolutions per second till the two halves of soil came in contact. The water content corresponding to 25 number of blows was recorded as the liquid limit of that sample. The values obtained are presented in table 3.3 for fly ash-bentonite mixtures and in table 3.4 for pond ash-bentonite mixtures.

Table 3.3: Liquid Limit of bentonite-fly ash mixtures

Sample Set 1	**LL(%)**
0% bentonite-fly ash mixture	51.5
2% bentonite-fly ash mixture	52.5
4% bentonite-fly ash mixture	53
8% bentonite-fly ash mixture	55
12% bentonite-fly ash mixture	64
20% bentonite-fly ash mixture	72

Table 3.4: Liquid Limit of bentonite-pond ash mixtures

Sample set 2	**LL(%)**
0% bentonite-pond ash mixture	36
2% bentonite-pond ash mixture	43
4% bentonite-pond ash mixture	46
8% bentonite –pond ash mixture	51
12% bentonite-pond ash mixture	56
20% bentonite-pond ash mixture	63

The liquid limit of bentonite was found to be 301%.

Fig. 3.7: Cone penetrometer

Fig 3.8: Cassagrande's Liquid Limit Device

3.4.1.2 Determination of Plastic Limit

Plastic limit represents the water content at which soil loses its plasticity and behaves like a brittle material when goes to semi solid state. It is also defined as the water content at which a soil would just begin to crumble when rolled into a thread of approximately 3 mm diameter. Tests were conducted to determine the plastic limit as per IS 2720(part V)-1985.

The plastic limit of the samples obtained are presented in tables 3.5 and 3.6.

Table 3.5: Plastic Limit of bentonite-fly ash mixture mixtures

Sample Set 1	**PL(%)**
0% bentonite-fly ash mixture	Non-plastic
2% bentonite-fly ash mixture	Non-plastic
4% bentonite-fly ash mixture	Non-plastic
8% bentonite-fly ash mixture	Non-plastic
12% bentonite-fly ash mixture	44
20% bentonite-fly ash mixture	45

Table 3.6: Plastic Limit of bentonite-pond ash mixtures

Sample Set 2	**PL(%)**
0% bentonite-pond ash mixture	Non-plastic
2% bentonite-pond ash mixture	Non-plastic
4% bentonite-pond ash mixture	Non-plastic
8% bentonite –pond ash mixture	Non-plastic
12% bentonite-pond ash mixture	29
20% bentonite-pond ash mixture	33.5

The Plastic Limit of bentonite was found to be 65%.

3.4.1.3 Determination of Plasticity Index

Plasticity Index (Ip) is obtained by calculating the difference between Liquid Limit and Plastic Limit. The values for different samples are presented in tables 3.7 and 3.8.

Table 3.7: Plasticity Index of bentonite-fly ash mixtures

Sample Set 1	**PI(%)**
0% bentonite-fly ash mixture	Non-plastic
2% bentonite-fly ash mixture	Non-plastic
4% bentonite-fly ash mixture	Non-plastic
8% bentonite-fly ash mixture	Non-plastic
12% bentonite-fly ash mixture	20
20% bentonite-fly ash mixture	27

Table 3.8: Plasticity Index of bentonite-pond ash mixtures

Sample Set 2	**PI(%)**
0% bentonite-pond ash mixture	Non-plastic
2% bentonite-pond ash mixture	Non-plastic
4% bentonite-pond ash mixture	Non-plastic
8% bentonite-pond ash mixture	Non-plastic
12% bentonite-pond ash mixture	27
20% bentonite-pond ash mixture	32.5

The Plasticity Index of bentonite was found to be 236%.

3.4.1.3 Determination of Shrinkage Limit

Shrinkage limit was determined as per IS 2720 (part VI) 1972 with the help of shrinkage dish as shown in the fig. 3.9. The sample preparation involved taking about 30 g of dry sample passing through 425 micron IS sieve and thoroughly mixing with distilled water to form a paste, which was left standing for 24 hours. The consistency of the paste was workable enough to place it in the shrinkage dish without entrapping air bubbles. Since bentonite was being tested, the water added was about 5%-10% more than the liquid limit. The specimen were tested and the values of shrinkage limit obtained are presented in the tables 3.9, 3.10 and 3.11.

Table 3.9: Shrinkage Limit of materials

Material	**SL(%)**
Fly ash	41.5
Pond ash	28
Bentonite	5

Table 3.10: Shrinkage Limit of bentonite-fly ash mixtures

Sample set 1	**SL(%)**
2% bentonite-fly ash mixture	41
4% bentonite-fly ash mixture	40
8% bentonite-fly ash mixture	39
12% bentonite-fly ash mixture	38
20% bentonite-fly ash mixture	36.5

Table 3.11: Shrinkage Limit of bentonite-pond ash mixtures

Sample set 2	**SL(%)**
2% bentonite-pond ash mixture	27
4% bentonite-pond ash mixture	26
8% bentonite-pond ash mixture	25
12% bentonite-pond ash mixture	23.5
20% bentonite-pond ash mixture	21.5

Fig. 3.9 Shrinkage dish

3.4.2 Determination of Differential Free Swell

Differential Free Swell was determined according to IS 2720 (part XL)-1977. For the test two oven dried sample passing through 425 micron IS sieve weighing 20 g each were placed separately in two 100 ml graduated cylinder. Distilled water was used to fill one cylinder and kerosene was used to fill another, up to the 100 ml mark as shown in fig. 3.10. In case of bentonite 10 gm of sample were taken for the test. The final reading of volume of soil was taken after 24 hours to calculate free swell index. The percent differential free swell was calculated as :

$$DFS\ (\%) = [(V_d - V_k)/\ V_k] \times 100$$

Where,

V_d = The volume of sample noted from the graduated cylinder containing distilled water .

V_k = The volume of sample noted from graduated cylinder containing distilled kerosene.

The values of DFS for different specimen are listed in the tables 3.12, 3.13 and 3.14.

Table 3.12: DFS of materials

Material	**DFS(%)**
Fly ash	-
Pond ash	-
Bentonite	556

Table 3.13: DFS of bentonite-fly ash mixtures

Sample set 1	**DFS(%)**
2% bentonite-fly ash mixture	-
4% bentonite-fly ash mixture	31.5
8% bentonite-fly ash mixture	86
12% bentonite-fly ash mixture	137
20% bentonite-fly ash mixture	178

Table 3.14: DFS of bentonite-pond ash mixtures

Sample set 2	**DFS(%)**
2% bentonite-pond ash mixture	-
4% bentonite-pond ash mixture	52
8% bentonite-pond ash mixture	121
12% bentonite-pond ash mixture	194
20% bentonite-pond ash mixture	251

Fig.3.10 Determination of DFS

3.4.3 Determination of Linear Shrinkage

Tests for Linear Shrinkage were conducted in moulds specified by IS 12979,1990. Paste samples were prepared by mixing 150 gm of material passing 425 micron IS sieve with water, approximately 2% above the liquid limit and left to stand for 24 hours. The paste was placed in the shrinkage mould as shown in fig.3.11 and then gently jarred to remove any air pockets in the paste. It was leveled off along the top of the mould with the palette knife. The mould was placed so that the paste could air dry slowly, until the soil had shrunk away from the walls of the mould. Drying of the mould first started at a temperature of 60 to 65°C until shrinkage had largely ceased and then at 105 to 110°C to complete the drying. After cooling of mould containing dried soil, the mean length of soil bar in the mould was measured by vernier caliper, if the specimen had curved during drying, the measurement should be made along the mean arc. The linear shrinkage of the soil was calculated from the following formula:

$LSI (\%) = [1 - (L_{avg}/ L_o)] \times 100$

Where,

L_{avg} = Average length of soil (mm)

L_o = Original length of brass mould (mm)

Fig.3.11: Linear Shrinkage mould

The values obtained for the materials and the coal ash-bentonite mixtures are listed in the tables 3.15, 3.16 and 3.17.

Table 3.15: Linear Shrinkage of materials

Material	**L_S(%)**
Fly ash	1.06
Pond ash	1.88
Bentonite	44.65

Table 3.16: Linear Shrinkage of bentonite-fly ash mixtures

Sample set 1	**L_S(%)**
2% bentonite-fly ash mixture	2.05
4% bentonite-fly ash mixture	3.04
8% bentonite-fly ash mixture	3.83
12% bentonite-fly ash mixture	5.55
20% bentonite-fly ash mixture	7.93

Table 3.17: Linear Shrinkage of bentonite-pond ash mixtures

Sample set 2	**L_S(%)**
2% bentonite-pond ash mixture	3.01
4% bentonite-pond ash mixture	4.32
8% bentonite-pond ash mixture	5.79
12% bentonite-pond ash mixture	7.11
20% bentonite-pond ash mixture	9.20

3.4.4 Determination of Compaction characteristics

Samples were prepared in 2 sets, set 1 consisted of bentonite-fly ash mixture and set 2 consisted of bentonite-pond ash mixture. Specimens were prepared by mixing bentonite to coal ash in the amount of 2%, 4%, 8%, 12% and 20% by its dry weight. Compaction tests were conducted after 24 hours of saturation period.

3.4.4.1 Light Compaction Test

The moisture content and dry density relationships were found out by Light compaction test according to IS 2720 (part VII) 1980. The MDD and OMC of fly ash, pond ash and bentonite obtained are listed in table 3.18.

Table 3.18: Compaction Characteristics of materials

Material	**MDD(g/cc)**	**OMC(%)**
Fly ash	1.158	40
Pond ash	1.186	27
Bentonite	1.38	32

The results obtained are listed in table 3.19 for bentonite-fly ash mixture and in table 3.20 for bentonite-pond ash mixture respectively.

Table 3.19: Compaction Characteristics of bentonite-fly ash mixtures.

Sample set 1	**MDD(g/cc)**	**OMC(%)**
2% bentonite-fly ash mixture	1.195	39
4% bentonite-fly ash mixture	1.221	37
8% bentonite-fly ash mixture	1.249	35
12% bentonite-fly ash mixture	1.262	34.5
20% bentonite-fly ash mixture	1.3	33

Table 3.20: Compaction Characteristics of bentonite-pond ash mixtures

Sample set 2	**MDD(g/cc)**	**OMC(%)**
2% bentonite-pond ash mixture	1.221	27
4% bentonite-pond ash mixture	1.271	23
8% bentonite-pond ash mixture	1.33	22
12% bentonite-pond ash mixture	1.357	21.5
20% bentonite-pond ash mixture	1.38	21

3.4.4.2 Heavy Compaction Test

The moisture content and dry density relationships were found out by Heavy compaction test according to IS 2720 (part II) 1973. The MDD and OMC of fly ash and pond ash obtained are listed in table 3.21.

Table 3.21: Compaction Characteristics of materials

Material	MDD(g/cc)	OMC(%)
Fly ash	1.29	30
Pond ash	1.32	22

The results obtained are listed in table 3.22 for bentonite-fly ash mixture and in table 3.23 for bentonite-pond ash mixture respectively.

Table 3.22: Compaction Characteristics of bentonite-fly ash mixtures.

Sample set 1	MDD(g/cc)	OMC(%)
2% bentonite-fly ash mixture	1.32	29
4% bentonite-fly ash mixture	1.34	28.5
8% bentonite-fly ash mixture	1.378	27.5
12% bentonite-fly ash mixture	1.404	26.5
20% bentonite-fly ash mixture	1.424	26

Table 3.23: Compaction Characteristics of bentonite-pond ash mixtures

Sample set 2	MDD(g/cc)	OMC(%)
2% bentonite-pond ash mixture	1.33	20.5
4% bentonite-pond ash mixture	1.34	18.5
8% bentonite-pond ash mixture	1.381	18
12% bentonite-pond ash mixture	1.410	17.5
20% bentonite-pond ash mixture	1.38	17

3.4.5 Determination of Unconfined Compressive Strength

The Unconfined Compressive Strength test was conducted according to IS 2720(part X) to study the strength characteristics of compacted coal ash-bentonite mixtures. For testing samples were prepared by mixing and compacting them at their corresponding MDD and OMC from light compaction test and were left for 24 hours for maturing. The test specimens of diameter 50 mm and height 100 mm were sheared at an axial strain rate of 1.25 mm/min till failure of the sample occurred. The unconfined compressive strengths of specimens were determined from stress versus strain curves and the failure stress and corresponding failure strain for 0 day at a compactive energy of 595KJ/m^3. The UCS values of bentonite blended with fly ash and pond ash are listed in table 3.24 and table 3.25 respectively.

Table 3.24: UCS of bentonite-fly ash mixtures

Sample Set 1	**UCS (kPa)**
0% bentonite-fly ash mixture	290.277
2% bentonite-fly ash mixture	323.619
4% bentonite-fly ash mixture	335.387
8% bentonite-fly ash mixture	347.155
12% bentonite-fly ash mixture	355.98
20% bentonite-fly ash mixture	423.647

Table 3.25: UCS of bentonite-pond ash mixtures

Sample Set 2	UCS (kPa)
0% bentonite-pond ash mixture	47.579
2% bentonite-pond ash mixture	52.876
4% bentonite- pond ash mixture	79.952
8% bentonite- pond ash mixture	137.34
12% bentonite- pond ash mixture	215.82
20% bentonite- pond ash mixture	289.395

3.4.6 Determination of Permeability

Permeability characteristic is the most important feature to be considered while engineering liner material. The coefficient of permeability of specimens were determined as per IS: 2720 (PartXVII) 1986 by Constant Head Permeability method. Samples were prepared by mixing and compacting them at MDD and OMC to the wet side of optimum in permeability moulds of diamter 10 cm and height 12.5 cm as shown in fig.3.12.

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Fig.3.12 Permeability mould

The average value of coefficient of permeability of the sample set 1 consisiting of compacted bentonite-fly ash mixture is presented in table 3.26 and that of sample set 2 consisting of compacted bentonite-pond ash mixtures is presesnted in table 3.27.

Table 3.26: Permeability characteristics of bentonite-fly ash mixtures

Sample Set 1	**Coefficient of Permeablity(cm/sec)**
0% bentonite-fly ash mixture	133×10^{-7}
2% bentonite-fly ash mixture	125×10^{-7}
4% bentonite-fly ash mixture	123×10^{-7}
8% bentonite-fly ash mixture	110×10^{-7}
12% bentonite-fly ash mixture	9.99×10^{-7}
20% bentonite-fly ash mixture	0.66×10^{-7}

Table 3.27: Permeability characteristics of bentonite-pond ash mixtures

Sample Set 2	**Coefficient of Permeablity(cm/sec)**
0% bentonite-pond ash mixture	1384.5×10^{-7}
2% bentonite-pond ash mixture	322.78×10^{-7}
4% bentonite- pond ash mixture	12.414×10^{-7}
8% bentonite- pond ash mixture	1.541×10^{-7}
12% bentonite- pond ash mixture	0.502×10^{-7}
20% bentonite- pond ash mixture	0.198×10^{-7}

Fig.3.13 Constant Head Permeability experimental setup

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

Experiments were conducted on coal ash mixed with various proportions of bentonite to explore their potential as liner material. The detailed description of the results obtained are discussed and presented in this chapter

4.2 INDEX PROPERTIES

4.2.1 Specific Gravity

The specific gravity of fly ash, pond ash and bentonite was determined according to IS 2720(part III/sec 1) by density bottle method. Kerosene was used in case of bentonite, which had the highest value of all with an average specific gravity of 2.89. Specific gravity is one of the important physical properties for soil to be considered as liner material. The average specific gravity of fly ash was found to be 2.33 whereas that of pond ash was 1.95. Pond ash had less specific gravity than fly ash because of it being more porous than fly ash. With the addition of bentonite to the coal ash there was an increase in the average specific gravity of the mixture.

4.2.2 Grain Size Distribution

Grain size distribution curve gives us an idea about the type and gradation of the soil. It indicates whether a material is well graded, poorly graded, uniformly graded, fine or coarse. The grain size distribution curves of fly ash and pond ash shown in the figures 3.5 and 3.6, are that of a well graded soil comprising particles of different sizes. Such materials compact well. Figure 3.7 showed the particle size distribution of bentonite which represented that of a fine grained soil consisting mainly of silt and clay sized particles.

4.3 ENGINEERING PROPERTIES

4.3.1 Atterberg Limits

4. 3.1.1 Liquid Limit

The Liquid limit of fly ash and pond ash were found to be 51.5% and 36% respectively which was very low compared to that of bentonite. Bentonite used for the project work had a liquid limit of 301%. The addition of bentonite to the coal ash increased the Liquid limit of the mixture considerably. The variation is presented in the figure 4.1 .

Where,

LL= Liquid Limit.

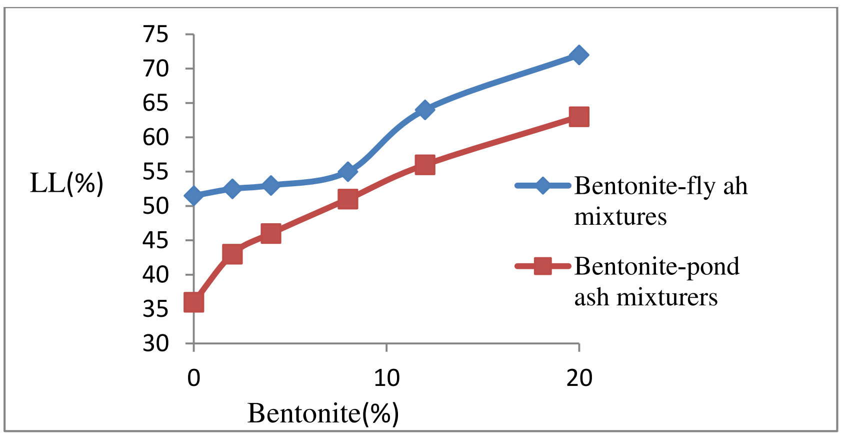

Fig.4.1Variation of Liquid Limit with bentonite content

4.3.1.2 Plastic Limit

The plastic limit of bentonite was found to be 65%. When it was added to the non-plastic coal ash, the mixture showed plasticity after about 12% of bentonite content in it. The results obtained are shown in the table 4.1.

Table 4.1 Variation of PL with bentonite content

Bentonite content(%)	PL of bentonite-fly ash mixture	PL of bentonite-pond ash mixture
12	44	29
20	45	33.5

4.3.1.3 Plasticity Index

Plasticity Index represents the range of moisture content over which a soil exhibits plasticity. The plasticity index of bentonite was found to be 236%. Both fly ash and pond ash are non plastic in nature which stabilized the highly plastic bentonite. Addition of fly ash reduces the thickness of the diffuse double layer clay particles, causing flocculation of clay particles, and increases the coarser particles content by substituting finer soil particles with coarser fly ash particles (Sivapullaiah et al. 1996). Plasticity in coal ash-bentonite mixture was seen after a bentonite content of 12% in it.

4.3.1.4 Shrinkage Limit

The liner material should posses low shrinkage ,for its functioning and durability. Bentonite exhibits high shrinkage upon slight increase in moisture content which leads to formation of shrinkage cracks. The shrinkage limit of bentonite was found out to be 5%. The mixture of coal ash and bentonite showed considerable increase in the shrinkage limit. The variations are presented in the figure 4.2.

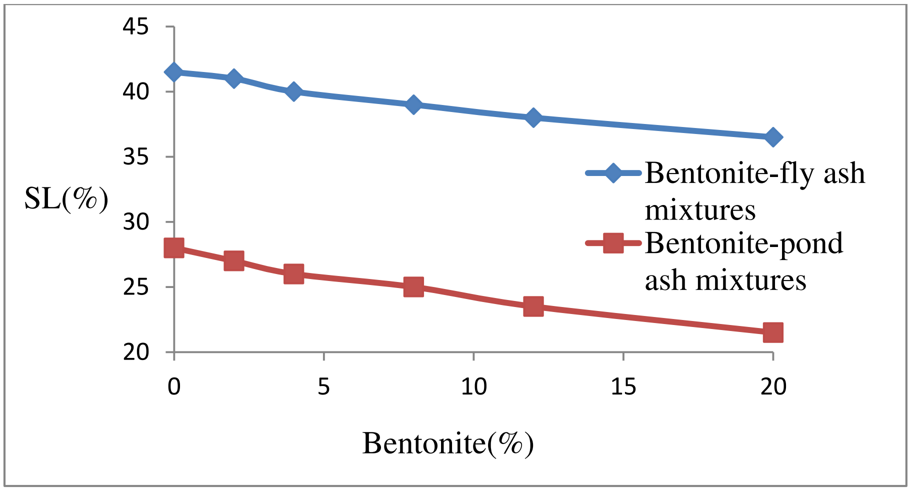

Fig.4.2Variation of Shrinkage Limit with bentonite content.

Where,

SL= Shrinkage Limit

4.3.2 Differential Free Swell(DFS)

Free swell is the increase in volume of a soil, without any external constraints, on submergence in water. The DFS of bentonite was found to be 556%. Bentonite shows very high swelling behavior because of its prominent cation exchange capacity. The variation of DFS with bentonite content is presented in the figure 4.3.

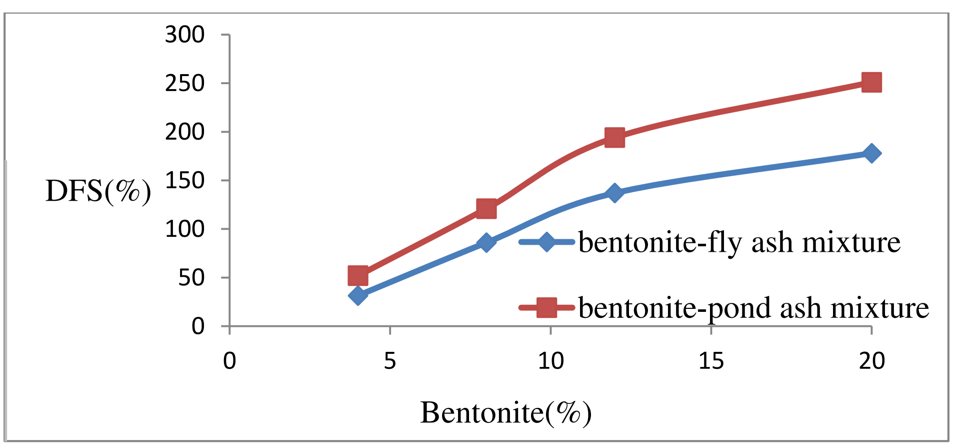

Fig. 4.3: Variation of DFS with bentonite content

4.3.3 Linear Shrinkage Index

In case of bentonite, formation of shrinkage cracks is the major issue to be tackled while considering it for waste containment liner. The bentonite used for the project work had a high linear shrinkage index of 44.65% and showed prominent desiccation cracks. When mixed with coal ash, there was a remarkable reduction in the shrinkage of the mixture. The linear shrinkage Index (L_S) remained within 10% for both the coal ash-bentonite mixtures. The variation is presented in the figure 4.4.

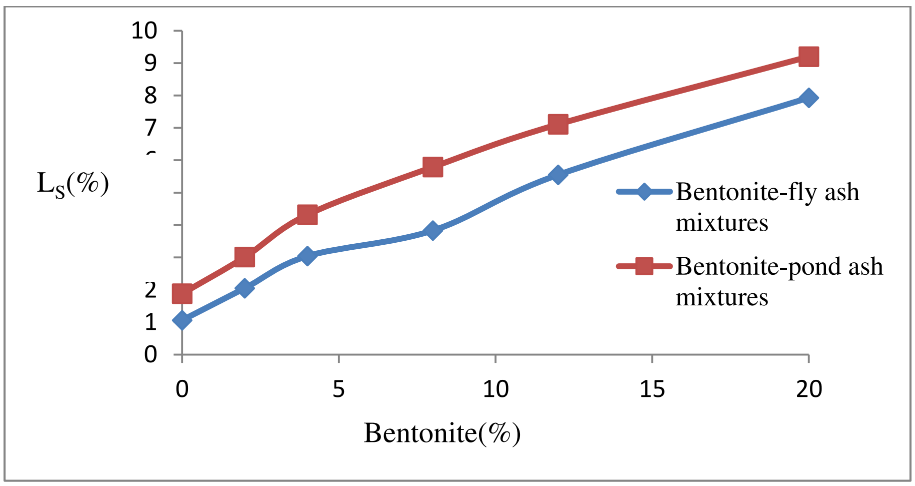

Fig.4.4: Variation of L_S with bentonite content

4.3.4 Compaction Characteristics

Light compaction test was carried out on specimens as per IS 2720 (part VII) 1980. The compaction curves for fly ash-bentonite mixture is presented in figure and that of pond ash-bentonite mixture is presented in figure 4.5 and 4.6 respectively.

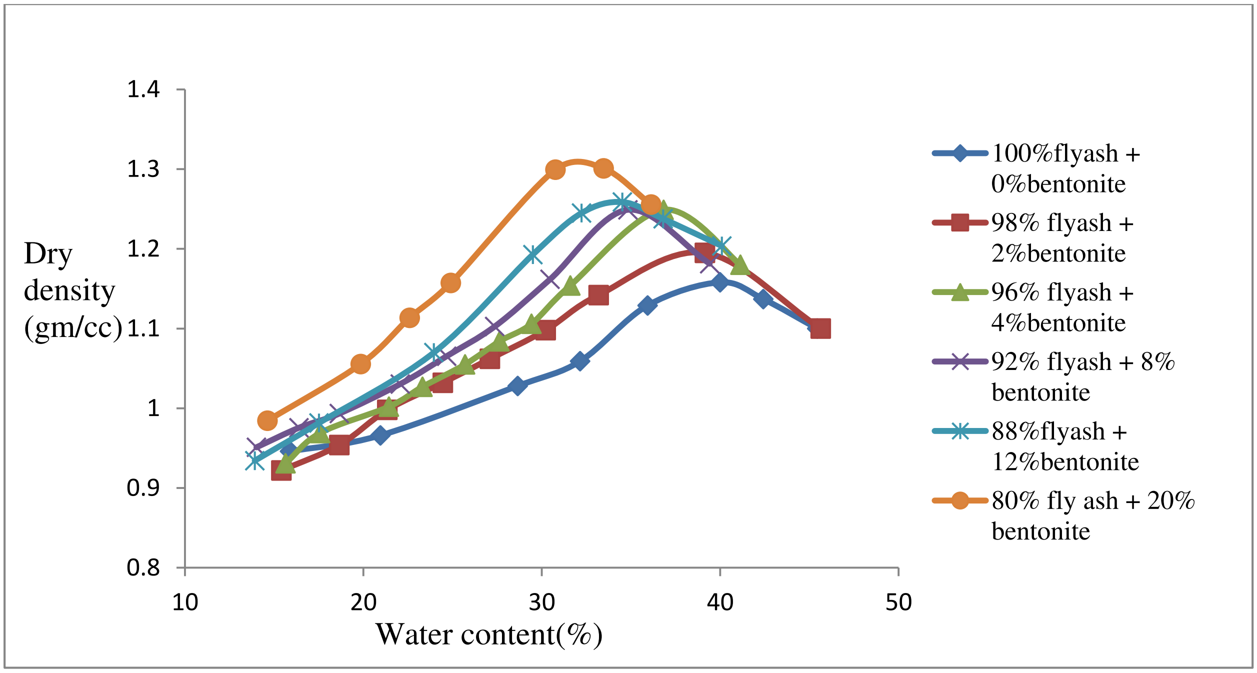

Fig. 4.5 Compaction curves of fly ash-bentonite mixtures under Light Compaction

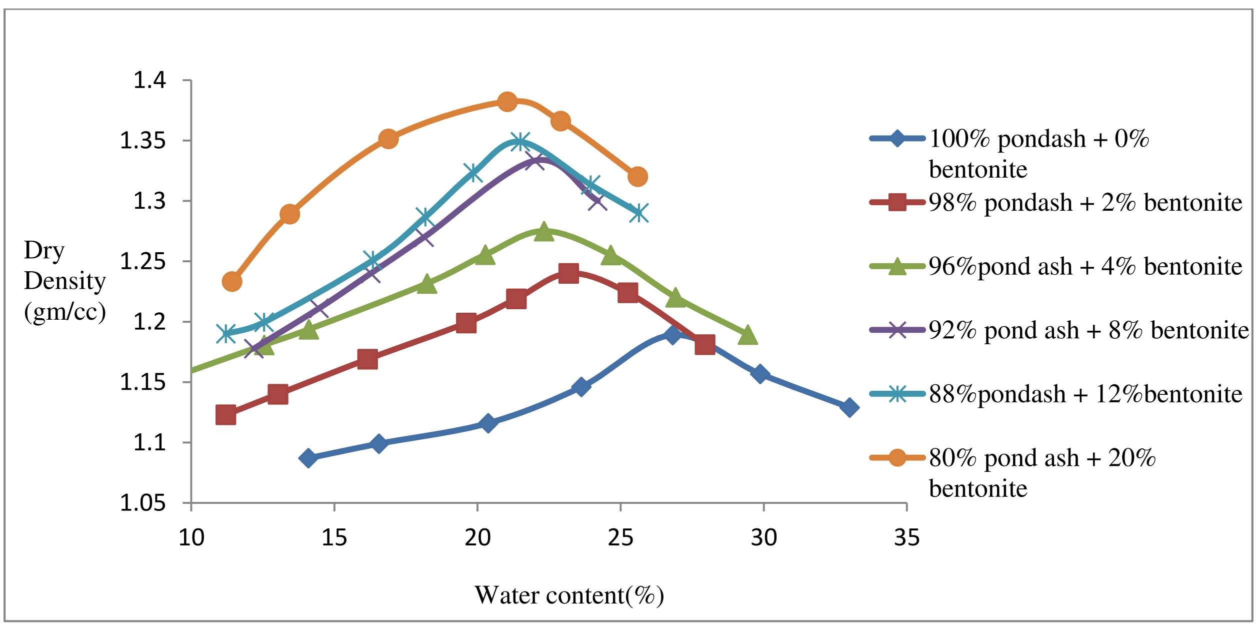

Fig. 4.6 Compaction curves of pond ash-bentonite mixtures under Light Compaction

The values of OMC and MDD obtained from laboratory compaction test provides a reference point while estimating the actual water content of the field-compacted soil liner. If the water content is not in the proper range, the engineering properties of the soil are not likely to be in the range desired. For example, if the soil is too wet, the shear strength of the soil may be too low. Similarly, the dry unit weight of the field-compacted soil may be compared to the maximum dry unit weight determined from a specified laboratory compaction test.

The variation of MDD and OMC of the compacted coal ash-bentonite mixtures are presented in the figures 4.7 and 4.8 respectively.

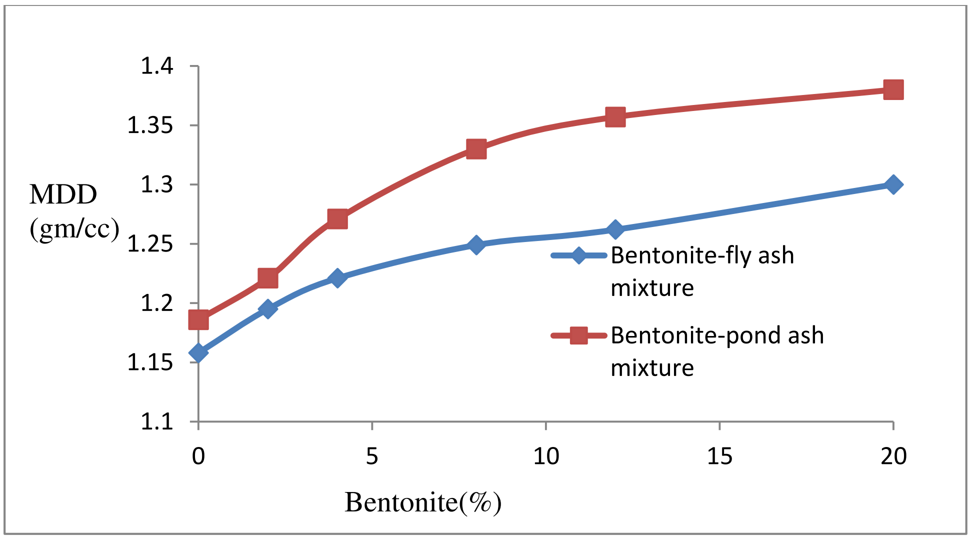

Fig. 4.7: Variation of MDD with bentonite content under Light Compation

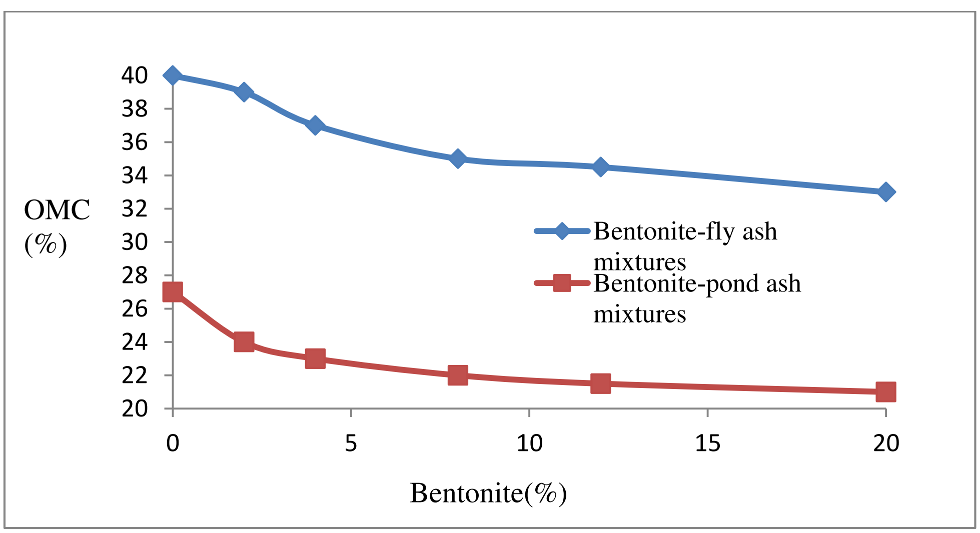

Fig. 4.8: Variation of OMC with bentonite content under Light Compaction

4.3.5 Unconfined Compressive Strength

The unconfined compressive strength tests were carried out on specimens prepared by compacting coal ash-bentonite mixtures at their MDD and OMC at a compactive energy of 593 kJ/m^3. The effect of adding bentonite on the UCS value of the mixtures are presented in the figure 4.9.

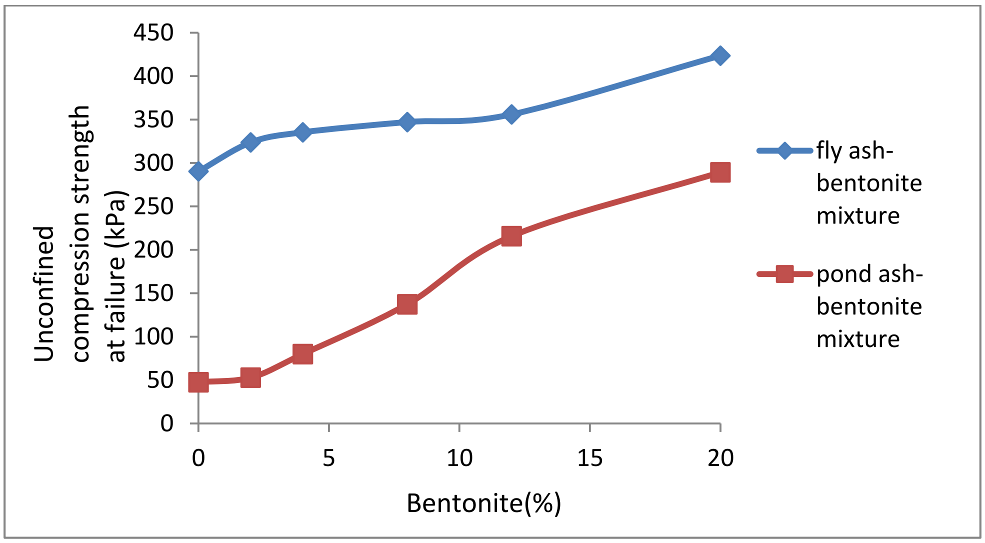

Fig. 4.9 Variation of UCS with bentonite content.

4.3.6 Permeability Characteristics

The average value of coefficient of permeability of flyash specimens were determined as per IS: 2720 (Part17) 1986 by Constant Head Permeability method. The varaiation of coefficient of permeability of fly ash-bentonite mixture and compacted pond ash-bentonite mixture compacted at the wet side of optimum is graphically presented in the figure 4.10.

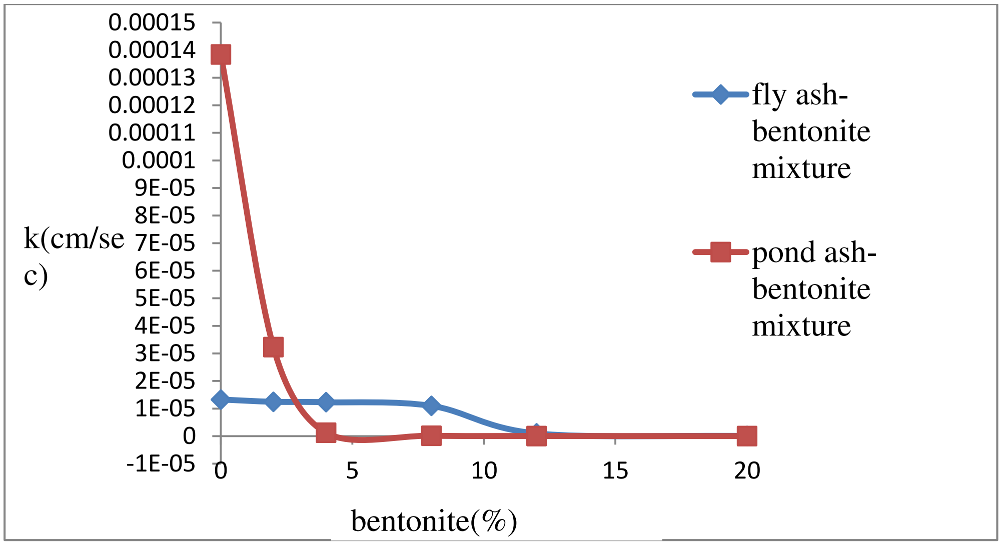

Fig. 4.10 Variation of permeability with increase in bentonite content.

It was reported that pond ash had higher permeability than fly ash because of it being more coarser. With the addition of 0-4% bentonite, compacted pond ash-bentonite mixture showed drastic reduction in the permeability, after which the value remained nearly constant. At about 12% bentonite content, it achieved a permeability of 0.5×10^{-7} cm/sec. Fly ash being finer showed a low permeability which gradually decreased with the addition of bentonite. The mixture of compacted 80% fly ash and 20% bentonite reported a permeability of 0.66×10^{-7} cm/sec.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Based on the experiments done on compacted coal ash amended with bentonite following results were drawn.

- The maximum dry density of both the coal ash increased and the OMC decreased with the increase in bentonite content. In case of pond ash-bentonite mixture similar value of MDD was achieved with a lower OMC of 26% than that of fly ash-bentonite mixture.
- As the bentonite content increased in the compacted mixture , the permeability decreased. 20% bentonite-fly ash mixture showed a permeability less than 1×10^{-7} cm/sec, which fulfilled the criteria for landfill liner. Whereas for pond ash, it was achieved at 12% bentonite content in the mixture.
- An increase in bentonite content of 12%-20% induced plasticity in the coal ash-bentonite mixture which led to better bonding between particles upon compaction.
- The Differential Free Swell of the mixture increased with the addition of bentonite, resulting as a better sealant.
- There was a variation in Shrinkage Limit and Linear Shrinkage in the coal ash-bentonite mixture with the addition of bentonite, without formation of prominent shrinkage cracks. In case of fly ash-bentonite mixture the variation of shrinkage limit fell in the range of 41%-36.5%. For pond ash blended with bentonite the range was 27%-21.5%.
- The UCS of compacted coal ash-bentonite mixture increased at a constant rate with the increase in bentonite content.

5.2 SCOPE FOR FUTURE WORK

- Consolidation test could be performed on compacted bentonite-coal ash mixtures to find out the compressibility and swelling pressure.
- Measurement of cracks can be done by the Cracking tests.
- Effect of lime and alkali on strength and durability of compacted clay liners could be investigated.
- Research work can be extended to see the effect of reinforcing plastic fibers in liner materials.

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